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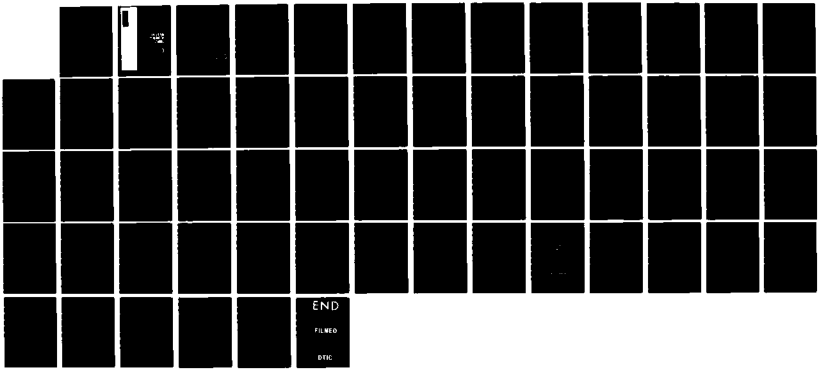

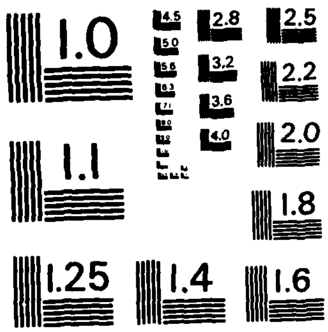

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Research Report CCS 513

A GOAL PROGRAMMING/CONSTRAINED REGRESSION REVIEW OF THE BELL SYSTEM BREAKUP

by

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(A)

ABSTRACT

The recently implemented U.S. court decision to break up Bell (=American Telephone & Telegraph Co.) to accord with U.S. anti-trust laws is also proving to be influential in other countries. Econometric studies commissioned by the Anti-Trust Division of the U.S. Justice Department used "flexible functional forms" to demonstrate that the evidence failed to show that Bell was a "natural monopoly". This same evidence is reviewed via goal programming/constrained regression models to reach an exactly opposite conclusion. The two approaches are compared and shortcomings and deficiencies in the econometric modeling, statistics and statistical (optimization) principles utilized in the Bell System studies are examined in detail. Additional keywords: cost models; econometric models; economic and statistical tests, tables (data), operations research.

KEY WORDS

Natural Monopoly

Production Function

Efficiency

Translog Flexible Functions

Goal Programming/Constrained Regressions

1. INTRODUCTION

Commenting in [19] on the production function concept of economic theory, we observed that there might be something of a misunderstanding when this concept was employed in studies of a policy variety. At that time the country -- indeed the world -- was grappling with an energy crisis when we observed that President Carter and Energy Czar Schlesinger, among others, kept referring to the need for reducing wasteful uses of energy while the economics studies they had ordered employed the concept of a production function in which, by definition, no waste is present.[1]

We have elsewhere reported on research directed toward the development of an alternative, "empirically based", production function that might be employed in empirical analyses which makes no such assumption -- see [16] -- and which, in fact, provides an operationally implementable method for identifying the sources and estimating the amounts of waste that might be present in observational data. This is not the only possible approach, however, and here we will take another tack to highlight some of the problems involved when the production function and related cost function concepts of economic theory are applied to empirical data.

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[1] I.e., in the terminology of economics, it is assumed that technical efficiency is always achieved and hence waste is absent. See Charnes, Cooper and Schinnar [19].

In this paper we focus on the breakup of the Bell Telephone System that was recently implemented as part of U.S. anti-trust policy. The center of attention will be on the empirical analysis by D. S. Evans and J. J. Heckman as reported in Breaking Up Bell [26]. Edited by Evans (of CERA Economic Consultants), this book is a compilation of essays prepared for the U.S. Justice Department to obtain required (or desired) economic analyses to guide or support the Goverment's case. To quote from its accompanying advertisement:

> "Breaking Up Bell is a compilation of nine essays written by top-notch economists of the 'Chicago School' who were consultants to the Justice Department during U.S. versus AT&T... [and the book thus] offers authoritative economic analysis of one of the most celebrated antitrust cases in history...."

Chapter 10 by Evans and Heckman is especially important not only because it addresses the central economics issue of whether Bell constituted a "natural monopoly" with associated cost savings and benefits that might be lost with a breakup but also because it is almost the only one of the reports in Breaking Up Bell where a systematic and detailed empirical inquiry into these issues is undertaken.

To trace the implications of evidence that was employed we shall use the same functional form and employ the same concepts as Evans and Heckman. This does not mean that we agree with these concepts and choices of functional forms for such policy analysis, or that we would ourselves follow this route in other respects. Our purpose is rather to highlight possible sources of misunderstanding that may occur as a result of the kinds of methodologies employed in deriv-

ing estimates and making inferences from empirical data interpreted as evidence.

Almost all of the analyses (pro and con) in the Bell case were undertaken by economists and econometricians using techniques such as statistical (e.g. least squares) regressions and index number constructions that constitute the methodologies commonly employed for empirical analysis by economists[2]. To highlight what is involved in such choices of methodologies we shall use a different approach based on the methods of goal programming/constrained regression, as developed in operations research and management science -- see [15] and [21]. Using the same data and employing the same functional forms as Evans and Heckman we will then arrive at almost opposite conclusions by simply choosing this different methodology.

The possible biases involved in methods of analysis and estimation are closely allied to choices of the disciplines to be used. These methodology choices and their consequences are difficult to detect and discover by outsiders (and even by persons within a particular discipline) unless cross-checked by recourse to methodologies associated with other disciplines. This is the main message we seek to convey: At least when large issues of policy are to be guided by the resulting inferences, it will be generally be prudent not to rely

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[2] For an exception see J. R. Meyer et.al. [35], and for comments on some of the engineering studies that were conducted by AT&T, see [27, p.150] [26, p.253] and [22, p.10]

on only one discipline (e.g., economics) but also to have recourse to other disciplines which employ different methodologies. Cross checks can thereby be obtained to help guard against the kinds of concealment that might otherwise result from the different methodologies that these disciplines characteristically employ.

2. MULTI-PRODUCT COST MODEL AND DATA DETAILS

When technical efficiency (i.e. zero waste) can be assumed, the duality theory of Shephard [39] as employed in economics, makes it possible to proceed from production functions to cost functions, and *vice versa*.[3] The choice of which one to employ is only a matter of convenience since this duality theory also ensures consistency in the results.

Proceeding in this manner, as reported in [26], Evans and Heckman elected to use a cost rather than a production fucntion in the following "translog" form:

$$\begin{aligned} \ln C = {} & \alpha_0 + \sum_i \alpha_i \ln p_i + \sum_k \beta_k \ln q_k + \mu \ln T \\ & + 1/2 \sum_i \sum_j \gamma_{ij} \ln p_i \ln p_j \\ & + 1/2 \sum_k \sum_r \delta_{kr} \ln q_k \ln q_r \\ & + \sum_i \sum_k \rho_{ik} \ln p_i \ln q_k \\ & + \sum_i \lambda_i \ln p_i \ln T + \sum_k \theta_k \ln q_k \ln T \\ & + \tau [\ln T]^2 \end{aligned} \tag{1}$$

[3] Cf. McFadden [34]

where

p_i = price (an index number) of the i th input, i=1,2,3 for capital, labor, and materials, respectively.

q_k = quantity (an index number) of the k th output, k=1,2 for local and long distance service, respectively.

T = an index of technological change,

and the coefficients in (1) are to be estimated from observed values of these variables

This "translog function" is a so-called "flexible functional form" introduced (see [24]) to relax restrictions associated with other choices such as the widely used Cobb-Douglas[4] and the less widely used Constant Elasticity of Substitution (CES) forms The idea is to regard (1) as an approximation to a wide class of functions with Cobb-Douglas and CES forms as special cases that might be precipitated out when the data (and the statistical methodologies used) cause this to happen.[5] The large number of parameters available also makes it possible to test hypotheses in a unified manner that is beyond the

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[4] As we have elsewhere shown, however, the Cobb-Douglas form covers a much wider class of functions than might be supposed. See [18], for instance, in which we show that a natural formalization of the Cobb-Douglas function can be used to represent any homogeneous function or, for that matter, any differentiable function. See also the use of piecewise Cobb-Douglas forms in [9]and [20].

[5] Subsequent research has shown that these translog representation suffer from severe difficulties and are thus limited for many applications. See [13] and [31] and p.257 in Evans and Heckman [26]. See also Charnes, Cooper and Schinnar [19].

that is beyond the reach of other, more specialized (hence less flexible), functional forms.[6]

The translog representation (1) was selected by Evans and Heckman [26] after a study of other functional forms. These other possible choices are not discussed here. Instead we refer readers to the discussions in Evans and Heckman where, as noted on p.259 in [26], the formulation (1) was finally settled upon.

We also refer readers to Evans and Heckman [26] for further discussion of this choice of variables and the index number constructions used. The data we employ are also drawn from Evans and Heckman [26] and reproduced as Table A.1 in the Appendix to this article. Before proceeding further, however, remarks like the following need to be entered:

All data were checked by using the same efficiency assumptions as Evans and Heckman -- see Appendix Part Two -- and these results were also checked by reference to the report by Christensen et al [22], the source credited by Evans and Heckman for much of their data. This checking was deemed necessary because we uncovered errors in the course of our research on other parts of the Evans-Heckman analysis which made it apparent that further checks into the underlying data were needed. The corrections resulting from these data reviews are shown as parenthesized amounts in the body of Table A.1. and still

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[6] Of course, this also creates degrees-of-freedom difficulties in conducting statistical tests, as we shall see below.

further corrections are provided in Table A.3, which we shall set aside for attention later in this article. Here we note only that we will proceed with the uncorrected data, i.e., the data reported by Evans and Heckman, since our objective is to show the different results that can emerge with the same functional form, (1), applied to the same data with a different estimating methodology and with a different metric employed for the optimization.

This then is the course that we shall follow with one addition. By reference to Christensen et al [22] -- the source from which the Evans-Heckman data were derived -- we discovered that it was possible to extend the data beyond the 1977 cut-off data and on into 1978 and 1979. For some undisclosed reason, this was not done by Evans and Heckman in either [26] or [28] but we nevertheless use the opportunity that this provides for additional testing in the following manner. First we utilize only 1947-1977 data as did Evans and Heckman to effect our estimates in a manner that admits of straighforward comparisons with their results. Then we undertake extrapolations from both models, as estimated, to obtain comparisons with the observed values for 1978 and 1979. The latter kind of testing seems especially appropriate in this case since, after all, the points at issue turned on possible future behavior and this meant that testing by extrapolation should have been undertaken whenever possible. In any case this way of proceeding allows us to effect all of the wanted comparisons without introducing data differences that might cloud the results.

All of these topics are treated in the sections that follow. In preparation for these discussion we therefore conclude this section by graphically portraying the data for the years 1947-1977 in Figure 1, 2, 3 and 4. These portrayals exhibit unusually smooth behavior, perhaps reflecting some of the index number computations and adjustments that were used. Because these index numbers constituted "data", for these analyses, we also continue to use them and take advantage of the very smooth trends that are apparent in these Figures and move rather freely between time and the indicated inputs, outputs, prices, and costs.

Such graphic devices were not used by Evans and Heckman -- or other economists engaged in such studies -- but they were apparently aware of the way this behavior allowed them to move rather freely to and back over time. They were also probably aware of the striking changes in price behavior that occurred for the inputs during this period. They do not discuss this in explicit detail, however, and they also do not discuss aberrations in the behavior of the technological change index which is apparent over the years 1965-1967.[7]

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[7] This technological change index was obtained from Vinod [43], but the values in Table A.1 may (and probably do) contain errors of computation and/or data omission which we did not bother to check.

It is possible, of course, to carry this further into a comparison of the "cross elasticities" that are also recorded by Evans and Heckman on p.264 in [26]. They do not discuss these values, however, and so we also refrain from further comment and simply note that the above "own elasticities" are all negative, as required.

Next we provide a listing of the critical constraints as identified by their associated dual variables in Table 3. Starting from the bottom of Table 3, where results applicable to the conditions (v) appear, we may observe that the only constraints that are critical appear in years where errors in the data or aberrant behavior is noted. See Figure 1, 2, 3, 4 and Table A.1 in the Appendix of this article.

Moving up to the next box in Table 3 we come to the conditions (iv) on own price elasticities. The dual variables for the upper bounds are all zero and so these are lumped in the "others" row with the remaining zero dual variables. The lower bounds are critical for γ_{22} and γ_{33} but the dual variable values are relatively small so that tightening the bounds set by S_2 and S_3 in (iv) would have relatively little effect on the resulting total deviations -- a topic that we shall again turn to after the the immediately following section.

Differences are evident in the 2 sets of estimates recorded in Table 1 which include the following coefficient values:

Variable	Coefficient Values Constrained Regression	Evans and Heckman
q_2^2 = Toll²	5.656	-8.018
q_1^2 = Local²	4.546	-4.241
$q_1 q_2$ = Local Toll	-5.204	11.663

These coefficient values enter importantly into the returns-to-scope and scale analyses that we shall discuss in the next section. We therefore conclude this section by conducting the following comparison between our estimates of own price elasticities with those reported by Evans and Heckman :

TABLE 2

Own Price Elasticities

(1961)

	Constrained Regression	Evans and Heckman
Capital	-.236	-.056
Labor	-.299	-.151
Materials	-.107	-.590*

* This amount corrects for what seems to have been a decimal point error in Evans and Heckman [26].

Table 1

Estimated Cost Function Coefficients

	Constrained Regression	Evans and Heckman*
Constant	9.045	9.054
Capital	.450	.535
Labor	.449	.355
Toll	-.080	.260
Local	.799	.462
Technology	-.016	-.193
Capital^2	.141	.219
Labor^2	.113	.174
Capital-Labor	-.087	-.180
Toll^2	5.656	-8.018
Local^2	4.546	-4.241
Local-Toll	-5.204	11.663
Technology^2	.822	-.176
Capital-Toll	.988	.337
Capital-Local	-.135	-.359
Labor-Toll	-1.131	-.179
Labor-Local	.141	.164
Capital-Technology	-1.106	.083
Labor-Technology	1.281	-.057
Toll-Technolgy	-3.124	-1.404
Local-Technolgy	3.105	1.207

*Source: Evans and Heckman [26], p.260 and [28] p.622

We include both upper and lower bounds so that the resulting own price elasticities, $\eta_i = S_i\gamma_{ii}$, will satisfy $-1 \leq \eta_i \leq 0$.[17]

Finally, we also impose the condition $\partial^2C/\partial p_i^2 \leq 0$, which is necessary[18] for concavity of (1) in each of the 3 input prices. We do this by imposing the following conditions for each i=1,2,3:

(v) $$\alpha_i + \gamma_{ii}(\ln p_i - 1) + \sum_j \gamma_{ij} \ln p_j + \sum_k \rho_{ik} \ln q_k + \gamma_i \ln T \geq 0$$

This completes our model. We next use the data of Table A.1 in the Appendix to estimate parameter values by the usual goal programming methods[19] to obtain results that can be compared with those reported in Evans and Heckman [26]. For simplicity we use only one of the two cost functions preferred by Evans and Heckman -- viz., (1), above with allowance for first order serial correlation -- and obtain the comparison portrayed in Table 1 for each of the 21 parameter values estimated by Evans and Heckman.

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[17] A serious weakness of the translog cost function is that the translog model often produces positive own-price elasticities, a result that is inconsistent with the usual conditions of economic theory. See Caves et al [13].

[18] See Varian [42] p.55. Actually the condition in (v) is weaker than the condition $\partial^2C/\partial p_i^2 \leq 0$. See Appendix, Part 3. This condition is imposed mainly to control effects from aberrant data behavior such as is apparent from Figure 4 in the 1966 observation of the technological change index.

[19] See Armstrong and Kung [4] and [5] or Barrodale and Roberts [10] and [11]. See also Charnes, Cooper and Sueyoshi [21].

We also constrain the "own" price elasticities for each of the 3 factor inputs to be non-positive. For this we use the development provided in Christensen and Greene [23] p.660, and transform these conditions on price elasticities into the following:

$$-S_i^2 \leq \gamma_{ii} \leq -S_i(S_i-1)$$

as constraints which are directly applicable for estimates of the cost function coefficients.

The term on the right in these expressions guarantees non-positivity for each of these "own elasticities" and we have introduced the term on the left in order to provide a lower limit by reference to the cost share conditions. Because we are not explicitly constraining the S_i values for cost shares, which may vary by year, we choose the lowest of the following range of possible cost share values: [16]

Cost Share ($=S_i$)	Min.	Max.
Capital	.39552	.56240
Labor	.32693	.49635
Material	.09950	.14108

Formally,

$$\text{(iv)} \quad -S_i^{*2} \leq \gamma_{ii} \leq -S_i^*(S_i^*-1)$$

$$\text{where} \quad S_i^* = \min_t S_{it} \quad \text{for} \quad t=1,2,\cdots,n.$$

[16] As reported in Christensen et al [22] p. 54. See also Evans and Heckman [26] p.277.

cost functions so that they will coincide with efficiency frontiers. They are thus required to assume that their observations scatter about the fitted function in a random fashion -- i.e., without contamination by managerial errors or other sources of inefficiency. Without such suppositions none of the results of the micro-economic theory of production can be used in the manner employed by Evans and Heckman or by others who have essayed similar approaches.

The formulation in (2) provides a possible way of looking at the evidence[14] to see whether such "efficieny frontier" assumptions can be satisfied to a reasonable degree. Of course, other conditions must also be satisfied. Conditions like those in (i) and (ii) are cases in point if inferences are to be supported by economic theory. However, the reduction of least absolute value regressions to linear programming equivalents -- as was accomplished in [15][15] -- also provides a way to handle such added conditions by simply adjoining constraints (i) and (ii) to the formulation in (2).

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[14] As noted at the outset of this paper, the formulation in (2) is not the only way of achieving efficiency (frontier) properties. See Hanoch and Rothschild [32] for an example of an alternative route that was available at the time the studies we are examining were undertaken.

[15] The dual variable evaluators available as a byproduct from the resulting linear programming models provide important information that makes it possible to effect sensitivity analysis and to determine which constraints are binding in a straightforward manner. See, Charnes, Cooper and Sueyoshi [21].

4. A GOAL PROGRAMMING/CONSTRAINED REGRESSION ALTERNATIVE

The goal programming/constrained regression alternative we use admits of only one-sided deviations in the following formulation:

$$\begin{aligned} \text{minimize} \quad & \sum_{t=1}^{n} \delta_t \\ \text{subject to} \quad & f(C_t) + \delta_t = \ln C_t, \\ & \delta_t \geq 0, \quad t=1,2,\cdots,n. \end{aligned} \tag{2}$$

Here $f(C_t)$ is the translog function to be estimated, in the same form as (1), and $\ln C_t$ is the natural logarithm of C_t, the observed total cost in year t. Because the δ_t are all constrained to be non-negative, the estimated coefficient values must satisfy $f(C_t) \leq \ln(C_t)$ for every t. Solving for the minimizing objective in (2) thus provides coefficient values for our translog function that will yield estimates of total cost that are as close to the observed total costs as these constraints will allow. The thus estimated cost function possesses a frontier (=envelope) property relative to the observed costs. Following Aigner and Chu [2][13] we interpret this as an "efficient frontier" with $f(C_t) < \ln C_t$ representing some amount of inefficiency, whenever it occurs for any t.

Although not discussed explicitly in Evans and Heckman, the "producer economics" to which they refer defines the production and

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[13] See also [1] and [3].

unambiguous meaning in economics only if technical efficiency is achieved -- as is assumed, in Evans and Heckman [26] p. 255. This assumption is basic. Because it does not appear to have been tested or even examined in any of the pertinent economic studies, we shall try to develop our model in a way that casts some light on these issues, and others, too, that appear to have been neglected, overlooked, or assumed away in the economics-econometrics studies we are examming.

A. Homogeneity: The assumed satisfaction of (i) makes it possible to eliminate 7 more parameters in the following manner:

$$\sum_i \alpha_i = 1 \qquad \text{remove 1 parameter}$$

$$\sum_j \gamma_{ij} = 0 \qquad \text{remove 3 parameters}$$

$$\sum_i \rho_{ik} = 0 \qquad \text{remove 2 parameters}$$

$$\sum_j \lambda_j = 0 \qquad \text{remove 1 parameter}$$

B. Symmetry: The assumed satisfaction of (ii) makes it possible to remove 3 parameters, one for each pair

$$\gamma_{ij} = \gamma_{ji} \text{ when } i \neq j.$$

These reductions result in producing 10 degrees of freedom with 21 parameters to estimate from the 31 observations in Table A.1.

Assuming that the observations are normally distributed (in the statistical sense), Evans and Heckman are then able to effect a variety of statistical tests. In addition to the tests on the economics-econometrics issues referred to in the preceding paragraphs, this testing extended to the central economics issue involved in "Breaking Up Bell" -- viz., does the evidence show AT&T to be a "natural monopoly" exhibiting "economies of scale" and/or "economies of scope" that might be lost if the system were broken up ?

As pointed out in the beginning of this paper, we approach these same topics from a goal programming/constrained regression standpoint that will be developed in the next section. Here, however, we note that "economies of scale" and "economies of scope" have an

ular problems to be addressed, and this, too needs to be taken into account in any across-discipline studies that might be commissioned. Particular attention might then be given to differences that may emerge when different methodologies are applied to the same data, as well as to differences that may emerge from the different data that might form the center of attention and/or the different problems that might be addressed by different disciplines.[11]

Reliance on economic theory in this manner has various advantages in that its implications may provide possibilities for increasing the degrees of freedom needed to make statistically meaningful estimates from empirical data. As Evans and Heckman note, [26], p.140, "implications of producer economics provides a great deal of information [sic] which [can be added to the statistical analysis] to increase the degrees of freedom."[12] That is, assuming that conditions (i) and (ii) are satisfied makes it possible to reduce the number of parameters to be estimated from 32 to 21 in (1) as follows:

To start, the 32 parameters formally exhibited in (1) for i=1,2,3 and k=1,2 are reduced to 31 by assuming that $\rho_{12}=\rho_{21}$. Then for the conditions exhibited in (i) and (ii) we effect the following further tally:

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[11] See, e.g., the discussion of the engineering studies in Evans and Heckman [26] p.140 and 253 and Christensen et al [22] p.1 and footnote.

[12] See also Christensen and Green [23] p.662.

Estimation and testing of (iii) generally proceeds in a way that differs from what is done for (i) and (ii).[8] We shall therefore not discuss treatment of the conditions of (iii) explicitly but reserve this for a separate paper. See also the discussion in Part Two of the Appendix.

Attempting to secure estimates of the parameters in (1) that satisfy (i) and (ii), Evans and Heckman reach the following conclusion on p.263 of [26][9]: "We resoundingly reject the homogeneity and symmetry restrictions implied by producer [economic] theory [on the basis of the evidence]. They then go on to assert: "Like other researchers [in empirical uses of economic theory] we [nevertheless] restrict our cost function estimates to satisfy homogeneity and symmetry." See [29] p.620.

To put this in perspective, we might refer readers to the conference of economists discussed in [19] where, after noting the numerous very serious errors of prediction in extant econometric studies of energy problems the group concluded that economic theory (rather than energy studies) required further attention and repair. Primacy is thus accorded to the body of economic theory[10] rather than the partic-

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[8] In particular it is customary to treat one of the constraints in (iii) as a residual to be determined after parameters have been estimated for the other 2 constraints. See [22].

[9] The stasistical assumptions used are set forth on p. 258 in [26].

[10] See M. W. Reder [38] for a detailed and insightful discussion of the consequences that can attend such preoccupations with the body of economic theory.

3. ECONOMETRIC MODEL AND HYPOTHESES TESTS

For (1) to be a satisfactory cost function in the sense of economic theory, the parameter values must satisfy the following conditions:

(i) Linear homogeneity in input prices, which requires the parameter values to satisfy

$$\sum_i \alpha_i = 1, \ \sum_j \gamma_{ij} = 0, \ \sum_i \rho_{ik} = 0, \ \sum_i \lambda_i = 0$$

as may readily be verified from (1).

(ii) The Hessian matrix of the cost function must be symmetric with respect to input prices which, by reference to the cross derivatives on p_i and p_j, requires

$$\gamma_{ij} = \gamma_{ji}.$$

(iii) The following "cost share" conditions must also be satisfied

$$S_i = \frac{p_i x_i}{C} = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \sum_k \rho_{ik} + \lambda_i \ln T$$

See [26] p.255.

Economic theory requires satisfaction of still further conditions which will be discussed as they become pertinent, e.g., negative "own price" elasicities for the factor inputs. Delaying discussion of these further topics will allow us to focus on already present problems which arise from the fact that Table A.1 in our Appendix provides only 31 observations to estimate 31 parameters in (1) that must also satifsy the relations specified in (i), (ii) and (iii).

Figure 3 TIME TRENDS OF INPUT PRICES

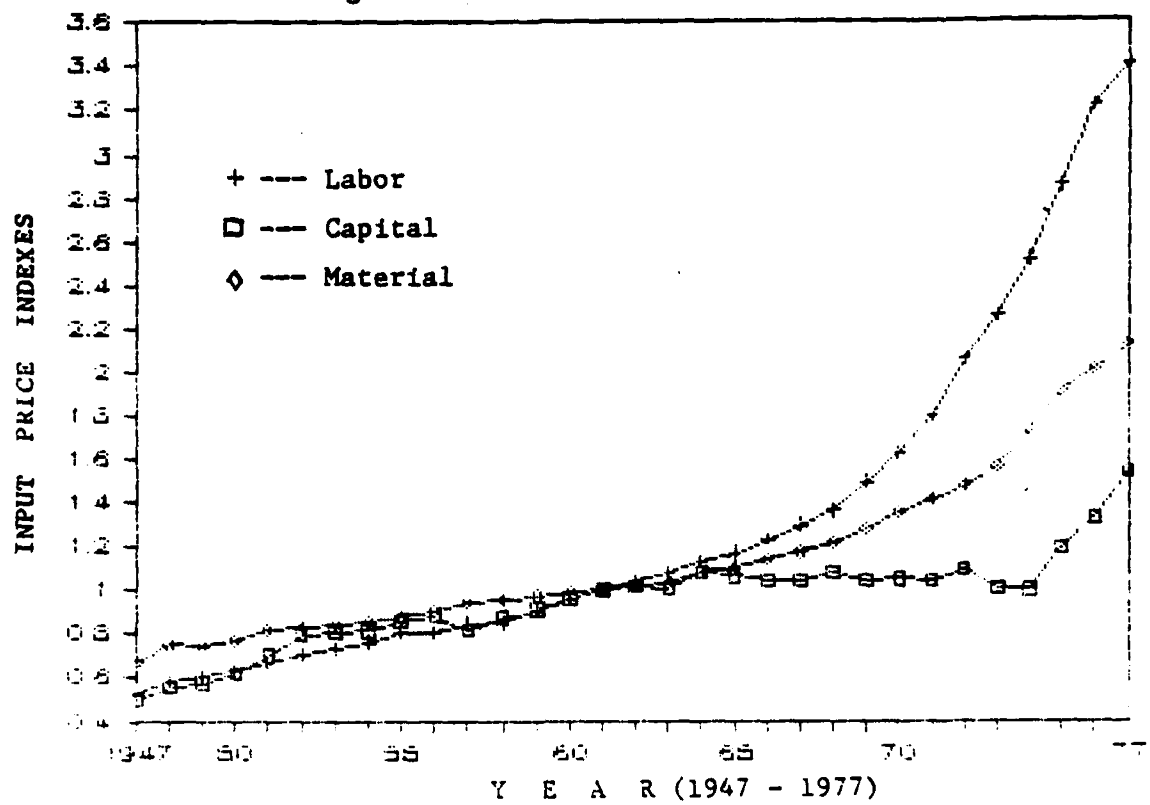

Figure 4 TIME TREND OF TECHNOLOGY

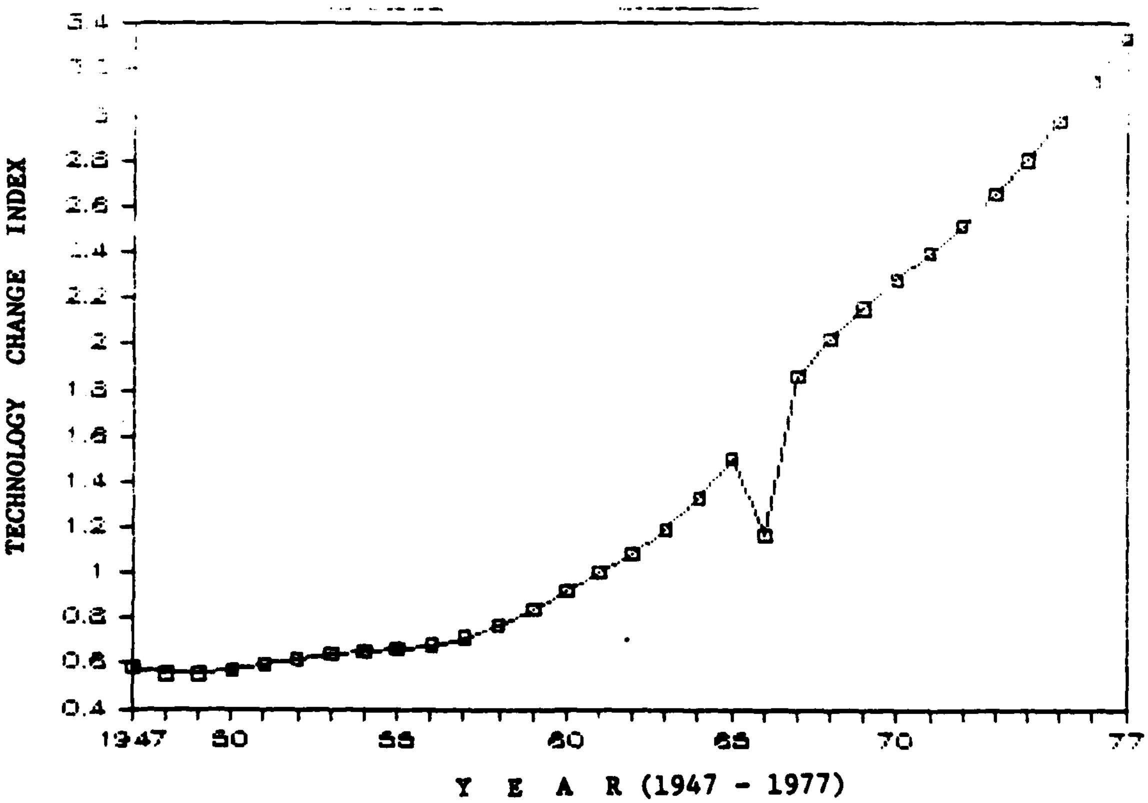

Figure 1 TIME TREND OF COST

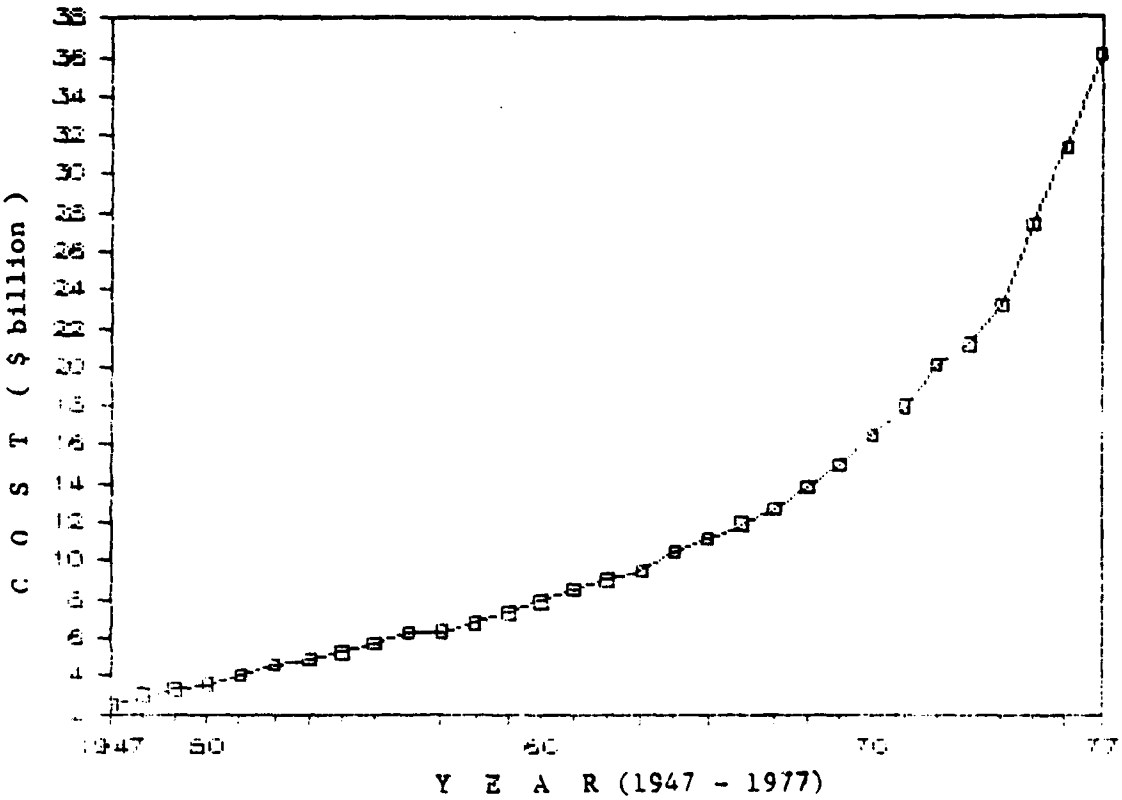

Figure 2 TIME TREND OF OUTPUT

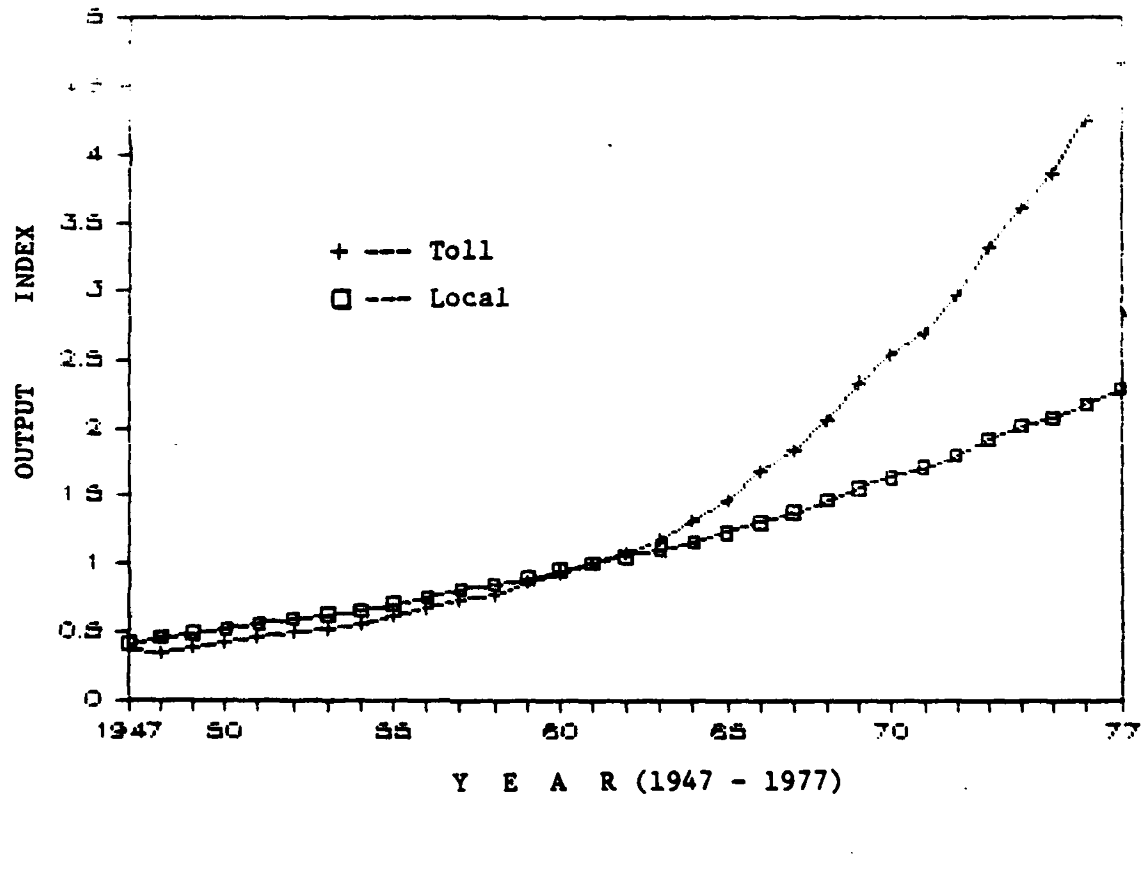

Table 3 Binding Constraint and Dual Variable Values

Observation and Constraints		Dual Variable
Observation	1947	.2884
	1948	-.9094
	1951	-3.5485
	1955	-1.4545
	1957	-.1678
	1960	-3.8156
	1963	-2.0713
	1966	.0019
	1967	.9257
	1968	-1.3451
	1969	-1.7240
	1972	-.1075
	1975	-2.4257
	1976	-.6466
	others	1.0000
Symmetry	(Cap.-Lab.) $\gamma_{12} = \gamma_{21}$	-.0490
	(Cap.-Mat.) $\gamma_{13} = \gamma_{31}$	-.0047
	(Lab.-Mat.) $\gamma_{23} = \gamma_{32}$	-.1018
Homogeneity	$\Sigma_j \alpha_j = 1$	.1235
	(Capital) $\Sigma_j \gamma_{1j} = 0$	-.0344
	(Labor) $\Sigma_j \gamma_{2j} = 0$	.1402
	(Material) $\Sigma_j \gamma_{3j} = 0$	.0934
	(Local) $\Sigma_j \rho_{j1} = 0$	.0847
	(Toll) $\Sigma_j \rho_{j2} = 0$	.1682
	(Technology) $\Sigma_j \lambda_j = 0$	.1387
Lower bound of γ_{ii}		
	(Labor²) $\gamma_{22} + S_2^{*2} \geq 0$	.0202
	(Material²) $\gamma_{33} + S_3^{*2} \geq 0$	.0844
	others	.0000
Price Concavity		
	1947 Material	.0321
	1948 Capital	.0156
	1948 Material	.0405
	1966 Labor	.0133
	1967 Material	.0207
	others	.0000

5. TESTS OF NATURAL MONOPOLY

The concept of "economies of scope" introduced by Baumol, et al[20] has pointed up the the need for extending analyses of "natural monopoly" beyond testings by reference only to "economies of scale." To clarify what is involved we follow Evans and Heckman [26], p.133, and say that economies of scope at output levels q_1 and q_2 are present if and only if

$$C(q_1, q_2) < C(q_1, 0) + C(0, q_2). \tag{3}$$

Verbally interpreted, this means it is less costly to produce outputs q_1 and q_2 together instead of separately. Several points need to be noted as follows: First, the functional forms are the same on both sides of (3) which means that the two entities with the cost functions represented on the right are assumed to have access to the same technology as the one entity on the left. Second, all entities are assumed to use the "best" or "most economical" technologies--i.e. the efficient frontier is always achieved.

[20] See [12]. See also Bailey and Friedlander [6]. We leave aside the problem of zero outputs in either q_1 and q_2 with logarithmic functions like (1) since this is not discussed in Evans and Heckman.

Concerning scale economies we again follow Evans and Heckman [26], p.282 and say that product specific scale economies[21] are present in product two if

$$\frac{C(q_1,q_2) - C(q_1,0)}{q_2} > \frac{\partial C}{\partial q_2} \qquad (4)$$

The increment to total cost associated with increasing the second output from 0 to q_2 while holding q_1 fixed is less than the average unit cost for q_2 throughout the range from 0 to q_2 where this occurs. Average cost will therefore fall if q_2 is increased in this manner.

A similar development holds for q_1, but the possibility of simultaneously incrementing q_1 and q_2 is omitted from consideration[22]. along with other possibilities like incrementing to q_2 from $q_2-\Delta q_2$ while holding q_1 fixed. The reason for limiting the analysis in this way is not clear since the "joint cost" possibilities associated with such variations were important considerations to the economic consequences of breaking up Bell. A possible reason for failure to treat this topic explicitly is that Evans and Heckman believed it was incorporated, along with economies of scale and scope, in their "natural monopoly" test which we summarize next.

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[21] Other more general formulations are available in Panzar and Willing [36]. See also the discussions in Banker, Charnes and Cooper [8] and Banker [7].

[22] See preceding footnote.

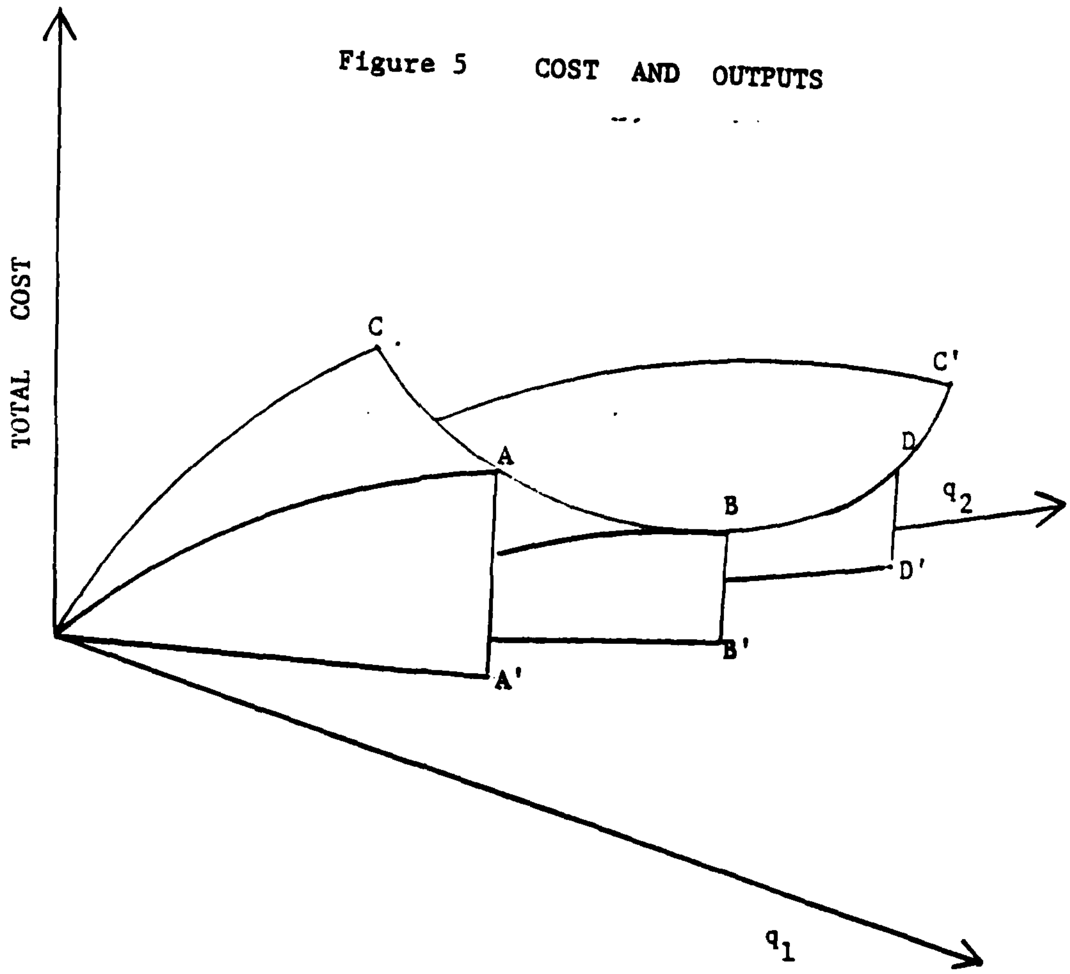
The concept of natural monopoly for a multi-product firm revolves around the mathematical concept of subadditivity -- viz, a function $C(q_1, q_2)$ is subadditive at (q_1, q_2) if and only if

$$C(q_1,q_2)=C[\alpha q_1+(1-\alpha)q_1,\beta q_2+(1-\beta)q_2] < C[\alpha q_1,\beta q_2]+C[(1-\alpha)q_1,(1-\beta)q_2] \qquad (5)$$

for $0 \leq \alpha, \beta \leq 1$.

Figure 5 provides a portrayal. Complete breakup would position the resulting two separate firms on the q_1 and q_2 axes, respectively, where they would each experience scale economies but not scope economies at $(q_1, 0)$ and $(0, q_2)$. For values of $0<\alpha, \beta<1$, total costs for each firm would be at values like A and D . The partial latitude to output choices that is thus allowed makes it possible to obtain some of the benefits of joint production without eliminating economies of scale. The lowest total cost occurs, however, at (q_1, q_2) where full advantage of economies of scope and of scale are both fully exploited.

Figure 5 COST AND OUTPUTS



To translate this portrayal into a form that can be applied to observational data and tested for statistical significance, Evans and Heckman develop a measure that they refer to as "sub_t (ϕ, ω)" in which ϕ and ω are counterparts to α and β in the above analysis and the subscript t refers to each of the years from 1958 to 1977. The reason for choosing these years and related statistical considerations and mathematical-economics developments are explained on p.266 in [26][23].

We do not repeat the Evans-Heckman development here, but simply reproduce the results which are reported on page 269 in [26] for each pair of ϕ and ω values used by Evans and Heckman in 1961. This is done in Table 4 where the resulting values represent estimates of gains that are possible from the indicated pairings. None of these values is statistically significant, but since they are all positive the evidence from this test indicates that the Bell System was <u>not</u> a natural monopoly, as Evans and Heckman observe. Nothing is lost and something might be gained in the way of cost savings by breaking up the entity.

Table 5 reports results from the same test applied to our constrained regression/goal programming approach. In this case the signs are all negative, so that a saving is indicated -- some of them quite substantial -- in every case. That is, the negative values in Table 5 represent estimated percentage losses via increased costs if Bell is

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[23] See also [28].

broken into two separate entities producing the mixture of toll and local calls indicated by the corresponding pairs of rim values.

Of course, the results in Table 5 are not decisive. More needs to be done not only with respect to significance testing but also with respect to local vs global properties that also need to be addressed. These additions to the present analysis would require substantial developments which we do not undertake because our main purpose has now been achieved. Exactly opposite conclusions may be obtained by simply changing the methods of estimation that are used. We further document this in Table 6, where, as may be observed, our results continue to contradict those of Evans and Heckman in every one of the pertinent years.

Table 4
Percent Gain or Loss from Multi Firm VS. Single Firm
Evans-Heckman [26] p. 269

ω / ϕ	Sub_{1961} x 100 (%)										
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.0	8										
0.1	8	8									
0.2	9	8	8								
0.3	12	10	9	9							
0.4	15	13	10	9	9						
0.5	20	16	13	11	9	9					
0.6	25	21	17	14	11	10	9				
0.7			23	18	15	12	10	9			
0.8					20	16	12	10	8		
0.9							17	13	10	8	
1.0										10	8

Note) Entries equal Sub_{1961} x 100. A positive number indicates that multi firm production is more efficient than single firm production.

Table 5
Percent Gain or Loss from Multi Firm VS. Single Firm
Constrained Regression

ω / ϕ	Sub_{1961} x 100 (%)										
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.0	-23										
0.1	-28	-20									
0.2	-34	-23	-18								
0.3	-41	-28	-20	-16							
0.4	-50	-34	-24	-18	-15						
0.5	-61	-41	-28	-21	-16	-15					
0.6	-73	-49	-34	-24	-18	-15	-15				
0.7			-41	-29	-21	-17	-15	-16			
0.8					-24	-18	-15	-15	-18		
0.9							-16	-15	-16	-20	
1.0										-17	-23

Note) Entries equal Sub_{1961} x 100. A negative number indicates that single firm production is more efficient than multi firm production.

Table 6

Maximum Percent Gain From Multifirm
VS. Single-Firm Production

Year	Constrained Regression	Evans and Heckman*
1958	-11	13
59	-15	20
60	-15	25
61	-15	25
62	-16	33
63	-19	40
64	-13	44
65	-15	48
66	-20	53
67	-23	58
68	-22	51
69	-29	50
70	-33	39
71	-42	36
72	-50	39
73	-63	41
74	-74	42
75	-69	45
76	-70	59
77	-58	51

Note) Entries equal Max Sub_t x 100 for each of t = 1958, •••, 1977. A positive number indicates that multifirm production is more cost efficient than single firm production and a negative value indicates that the opposite is true.

* From Evans and Heckman [28], 1984 p.620.

6. ECONOMIC AND STATISTICAL TESTS

Not tested, and not even examined, are the following two basic assumptions made by Evans and Heckman: (1) the "economics assumptions" of efficient production and (2) the "statistical assumption" of multi variate normality for the way errors in the data behave. We do not go into possible interactions between the two but only examine them separately.

Table 7 portrays observed costs under C_t and the corresponding estimates under $\widehat{C}_t$ from Goal Programming/Constrained Regression (G-P/C-R) and Evans and Heckman (E-H). An unusually large number of zeros can be seen under the G-P/C-R column, a behavior that is consistent with the hypothesized economic efficiency. Furthermore, as indicated by the G-P/C-R % deviations, the relative correspondences between the estimates and observed values are close with an estimated average absolute deviation of only 0.64%. Allowance for errors and aberrations such as the 1966 behavior of the technological change index might improve even this very good picture, but, in any event, the evidence seems remarkably consistent with the efficiency assumption.

Evans and Heckman fail to state what kind of efficiency[24] they are assumming, but we believe that it was probably technical (=zero waste) efficiency by virtue of the following reasons. Scale efficiency was a central issue for the Bell breakup case and hence could not be assumed without invalidating the whole analysis. Price or allocative efficiency presents a more clouded picture. No way is apparent for determining either the relevant planning period for cost minimization or the way in which the index numbers in the present study can be utilized for such purposes.[25] We therefore conclude that it is most meaningful to assume that technical efficiency[26] is what Evans and Heckman had in mind and note that this was reasonably well achieved by Bell, as measured by our G-P/C-R model.

The statistical assumptions of multivariate normality are another matter, as are related "regression assumptions" like (a) the absence of collinearity and (b) the absence of effects from "outliers" on their coefficient estimates. Although Evans and Heckman provide

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[24] We are referring to the concepts of technical, allocative, and scale efficiency which are now common in the literature of economics following Farrell [29], and Farrell and Fieldhouse [30].

[25] Actually Evans and Heckman did not even use their index number estimates correctly in the present study, as will be noted below in connection with Tables A.1 and A.2 in the Appendix.

[26] We are not distinguishing between "price efficiency" and "allocative efficiency" as in Sherman [40] who used this to distinguish between situations in which (a) lowest possible prices were paid and (b) the resources were allocated in every year to obtain the lowest total production cost at whatever prices were paid -- over the entire planning horizon.

extensive discussions of collinearity, these all take the form of criticisms directed to treatment proposed by others such as Vinod's use of "ridge regression."[27] Nothing is explicitly said by Evans and Heckman about any methods of their own so that issues such as bias and instability in their estimates of regression coefficients are left unattended in Chapter 10 of [26]. See also [28].

That such problems may be present is indicated by the comparison shown in the row labelled Total Absolute Value for the sums of residuals under the G-P/C-R and E-H columns. Because G-P/C-R utilizes a least absolute value measure, it is to be expected that the total of these residuals under G-P/C-R should be smaller than the amounts listed under E-H. However, a relative multiplying factor of more than 10 -- 2,200 vs. 23,000 -- is much too large than what might be expected from the different metrics utilized in these two different approaches in the presence of well behaved data.

Here we might note that the metric utilized by E-H is extremely sensitive to "outliers" whereas this is not the case for the absolute value metric used in G-P/C-R. Moreover, utilization of extreme point solution procedures such as the simplex method -- as was made possible by the transformations first published in [15] -- eliminates

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[27] See p.142 in [27].

the possiblility of strong collinearity.[28] Possibilities of weak collinearities, which remain, can then be detected and possibly repaired or otherwise allowed for by extensions to sensitivity analysis that are indicated in [21].

[28] Evans and Heckman seem to believe that collinearity is entirely a matter of the data. This is not correct. Collinearity is a problem caused by the data and/or the models used for estimation. Furthermore, a choice of solution method may also be pertinent since these methods may have mathematical properties that affect the admissible solutions, which is the reason why we have elsewhere insisted that choice of algorithms should be considered a part of the modeling process. See, e.g., the discussion of what we called "algorithmic completion of a model" in [14].

Table 7

Summary of Statistical Fit

Year	Observed Cost	G-P/C-R Constrained Regression		E-H Evans and Heckman		% Deviation	
t	C_t	$\widehat{C_t}$	$C_t - \widehat{C_t}$	$\widehat{C_t}$	$C_t - \widehat{C_t}$	G-P/C-R	E-H
1947	2550.68	2550.68	.00	1879.40	671.28	.00	35.72
48	2994.94	2994.94	.00	2890.94	104.00	.00	3.60
49	3291.06	3253.15	37.91	3115.75	175.31	1.16	5.63
50	3563.20	3556.14	7.06	3461.61	101.59	.20	2.93
51	4047.07	4047.07	.00	3952.11	94.96	.00	2.40
52	4616.23	4562.08	54.15	4568.15	48.08	1.19	1.05
53	4935.13	4837.82	97.31	4891.76	43.37	2.01	.89
54	5258.76	5129.20	129.56	5153.79	104.97	2.53	2.04
55	5770.47	5770.47	.00	5730.41	40.06	.00	.70
56	6305.44	6237.66	67.78	6160.70	144.74	1.09	2.35
57	6351.19	6351.19	.00	6307.81	43.38	.00	.69
58	6788.40	6689.44	98.96	6704.58	83.82	1.48	1.25
59	7334.71	7321.00	13.71	7384.25	-49.54	.19	-.67
60	7912.48	7912.48	.00	8004.12	-91.64	.00	-1.14
61	8516.46	8473.46	43.00	8552.68	-36.22	.51	-.42
62	9018.66	9000.99	17.67	9058.80	-40.14	.20	-.44
63	9508.12	9508.12	.00	9490.07	18.05	.00	.19
64	10524.00	10308.88	215.12	10478.10	45.90	2.09	.44
65	11207.00	10924.72	282.28	11026.22	180.78	2.58	1.64
66	11954.20	11954.20	.00	12018.94	-64.74	.00	-.54
67	12710.90	12710.90	.00	12584.04	126.86	.00	1.01
68	13814.10	13814.10	.00	13761.15	52.95	.00	.38
69	14940.40	14940.40	.00	15006.80	-66.40	.00	-.44
70	16485.80	16284.02	201.78	16577.44	-91.64	1.24	-.55
71	17951.80	17909.53	42.27	18492.86	-541.06	.24	-2.93
72	20161.20	20161.20	.00	21357.26	-1196.06	.00	-5.60
73	21221.70	21029.61	192.09	23800.05	-2578.35	.91	-10.83
74	23168.40	23101.55	66.85	27561.30	-4392.90	.29	-15.94
75	27376.70	27376.70	.00	31627.11	-4250.41	.00	-13.44
76	31304.50	31304.50	.00	35903.39	-4598.89	.00	-12.81
77	36078.00	35407.15	670.85	39542.76	-3464.76	1.89	-8.76
Total Absolute Value			2,238.35		23,542.85	0.64	4.43

* All costs are stated in millions of 1967 dollars.
See Appendix Table A.1. and A.2.

[22] because no particular reason for shifting to a 1961 base is given by Evans and Heckman.

As easy way to effect further adjustments is at hand in any case since

$$C_t = \sum_{i=1}^{3} p_{ti} q_{ti}$$

for each period t=1947,...,1977, where, for year t, q_{ti} represents the amount (=index number value) for i=capital, labor or materials, respectively, and p_{ti} represents the corresponding price. The latter, i.e. the unit price in each year, is stated relative to 1967 prices[1] in Table A.2 as may be verified--e.g., the "cost" obtained for the first row in Table A.2 is obtained via

$$2,101.8 \times 0.480 + 3,065.5 \times 0.413 + 462.7 \times 0.596 = 2,550.68,$$

which is the value recorded in the last column of this row. This value, in the terminology of economics, is to be interpreted as the "real cost" (=relative to 1967 prices) in units of $1,000,000.

This value is the same as the one shown in the first column of Table A.1. The input prices in Table A.1, however, were adjusted by Evans and Heckman to a 1961 base by dividing each input price recorded in Table A.2 by its corresponding 1961 value in Table A.2. Hence the

[1] See the input "prices" recorded for capital, labor and materials in the 1967 row.

PART TWO: DATA ADJUSTMENTS

Table A.1 is taken from Evans and Heckman [26] p.276-277, and contains the data used in this study. The parenthesized amounts indicate where errors were located in the course of our analyses and the corrected values are shown to their right. As already noted, we used only the original (uncorrected) data in this paper to obtain full comparability for the uses as reported by Evans and Heckman in [26]. See also [28].

Further, more serious, discrepancies were occasioned by the adjustments that Evans and Heckman effected (or rather failed to effect) in transferring the data from Christensen, et al [22]. The latter data are reproduced in Table A.2 with all price indexes referred to a 1967 base period as can be seen in this row of Table A.2. Evans and Heckman preferred a 1961 base period, however, and adjusted the input prices accordingly. They failed to make the corresponding adjustment for costs, however, as can be seen by noting that the costs reported for each year in Table A.1 ostensibly on a 1961 base, are the same as the costs in the column labelled Real Cost in Table A.2 which are on a 1967 base.

Christensen, et al do not decompose total output into its local and toll components so we have undertaken to complete the picture in Table A.3 for convenience in use by potentially interested persons. The choice of a base period being essentially arbitrary, we elected to relate all prices to 1967 as a base as in Christensen et al

Table A.3

Bell System Data Corrected
(1967 Base Period)

Year	Cost ($\$10^6$)	Local Output	Toll Output	Capital Price	Labor Price	Materials Price	R&D Index	Capital Share	Labor Share	Materials Share
1947	2550.68	.297	.188	.480	.413	.596	.310	.396	.496	.108
1948	2994.94	.331	.202	.537	.449	.640	.297	.404	.483	.113
1949	3291.06	.352	.208	.552	.470	.635	.296	.419	.471	.110
1950	3563.20	.376	.226	.594	.487	.652	.305	.441	.453	.106
1951	4047.07	.402	.253	.673	.516	.695	.319	.453	.442	.104
1952	4616.23	.428	.272	.764	.547	.706	.332	.467	.432	.102
1953	4935.13	.452	.284	.777	.566	.719	.342	.464	.436	.099
1954	5258.76	.475	.298	.781	.587	.729	.348	.466	.428	.105
1955	5770.47	.508	.336	.827	.622	.746	.354	.478	.414	.108
1956	6305.44	.547	.371	.846	.625	.771	.364	.477	.410	.113
1957	6351.19	.581	.402	.788	.654	.800	.382	.471	.414	.115
1958	6788.40	.609	.421	.839	.656	.812	.411	.508	.388	.104
1959	7334.71	.648	.468	.875	.709	.830	.449	.520	.373	.106
1960	7912.48	.689	.507	.920	.740	.844	.492	.531	.361	.108
1961	8516.46	.723	.543	.961	.771	.852	.535	.544	.346	.110
1962	9018.66	.762	.587	.975	.799	.869	.581	.551	.340	.110
1963	9508.12	.803	.637	.969	.828	.881	.637	.551	.333	.115
1964	10542.48	.838	.715	1.036	.871	.924	.711	.562	.326	.112
1965	11206.97	.888	.800	1.020	.903	.943	.803	.553	.329	.118
1966	11954.19	.944	.914	1.004	.947	.972	.893	.543	.337	.120
1967	12710.90	1.000	1.000	1.000	1.000	1.000	1.000	.541	.341	.119
1968	13814.12	1.060	1.115	1.041	1.049	1.039	1.085	.546	.334	.120
1969	14940.44	1.127	1.267	1.005	1.152	1.093	1.158	.514	.358	.128
1970	16516.87	1.185	1.377	1.008	1.252	1.152	1.222	.497	.371	.132
1971	17951.82	1.236	1.464	1.000	1.391	1.210	1.285	.483	.383	.134
1972	20161.19	1.305	1.611	1.049	1.590	1.258	1.349	.479	.391	.130
1973	21190.30	1.382	1.800	.964	1.745	1.331	1.421	.446	.415	.139
1974	23168.36	1.452	1.956	.962	1.940	1.483	1.501	.434	.425	.141
1975	27376.69	1.500	2.097	1.143	2.201	1.630	1.591	.462	.406	.132
1976	31304.54	1.571	2.303	1.276	2.482	1.716	1.686	.470	.395	.135
1977	34745.33	1.657	2.542	1.364	2.627	1.814	1.784	.467	.393	.140

Table A.2

Input Quantities and Prices*

Year	Capital		Labor		Materials		Real Cost
t	Q_t	P_t	Q_t	P_t	Q_t	P_t	($\$10^6$)
1947	2101.8	.480	3065.5	.413	462.7	.596	2550.68
1948	2254.9	.537	3220.8	.449	528.0	.640	2994.94
1949	2500.3	.552	3299.0	.470	567.5	.635	3291.06
1950	2645.2	.594	3318.3	.487	576.6	.652	3563.20
1951	2726.4	.673	3469.1	.516	607.4	.695	4047.07
1952	2819.9	.764	3642.3	.547	665.0	.706	4616.23
1953	2949.4	.777	3802.9	.566	682.9	.719	4935.13
1954	3137.5	.781	3840.3	.587	760.1	.729	5258.76
1955	3338.1	.827	3842.1	.622	831.2	.746	5770.47
1956	3550.9	.846	4141.0	.625	925.1	.771	6305.44
1957	3799.3	.788	4017.1	.654	912.7	.800	6351.19
1958	4106.6	.839	4020.2	.656	869.1	.812	6788.40
1959	4361.5	.875	3861.0	.709	940.9	.830	7334.71
1960	4568.6	.920	3858.2	.740	1012.2	.844	7912.48
1961	4819.3	.961	3822.5	.771	1100.9	.852	8516.46
1962	5094.6	.975	3833.9	.799	1137.1	.869	9018.66
1963	5410.4	.969	3830.0	.828	1242.0	.881	9508.12
1964	5713.1	1.036	3950.3	.871	1280.3	.924	10542.48
1965	6074.5	1.020	4086.3	.903	1400.9	.943	11206.97
1966	6465.5	1.004	4253.8	.947	1475.8	.972	11954.19
1967	6874.0	1.000	4329.1	1.000	1507.8	1.000	12710.90
1968	7247.4	1.041	4399.3	1.049	1592.6	1.039	13814.12
1969	7641.6	1.005	4643.3	1.152	1748.9	1.093	14940.44
1970	8144.7	1.008	4889.6	1.252	1896.9	1.152	16516.87
1971	8673.2	1.000	4943.5	1.391	1985.3	1.210	17951.82
1972	9216.3	1.049	4953.0	1.590	2081.1	1.258	20161.19
1973	9809.3	.964	5035.7	1.745	2214.0	1.331	21190.30
1974	10453.9	.962	5073.8	1.940	2204.0	1.483	23168.36
1975	11060.5	1.143	5050.7	2.201	2219.6	1.630	27376.69
1976	11525.1	1.276	4983.1	2.482	2465.3	1.716	31304.54
1977	11899.0	1.364	5192.5	2.627	2687.1	1.814	34745.33

Legend Q = Quantity Index
P = Price Index (using 1967 as price relatives)

*Source : L. R. Christensen, D. Cummings and P. E. Schoech [21], 1981.

Table A.1

Bell System Data Used for

Multiproduct Cost Function Estimates*

Year	Cost ($\$10^6$)	Local Output	Toll Output	Capital Price	Labor Price	Material Price	R&D Index	Capital Share	Labor Share
1947	2550.68	.41014	(.36642) .34642	.49948	.53566	.66962	.57965	.39552	.49635
1948	2994.94	.45783	(.34642) .37201	.55879	.58236	.76117	.55445	.40430	.48286
1949	3291.06	.48703	.38296	.57440	.60959	.74530	.55261	.41936	.47113
1950	3563.20	.52004	.41592	.61810	.63164	.76525	.56980	.44096	.45352
1951	4047.07	.55560	.46552	.70031	.66926	.81572	.59576	.45338	.44230
1952	4616.23	.59149	.50116	.79500	.70946	.82863	.62067	.46670	.43159
1953	4935.13	.62452	.52271	.80853	.73411	.84389	.63873	.46436	.43614
1954	5258.76	.65669	.55000	.81269	.76134	.85563	.65059	.46596	.42866
1955	5770.47	.70289	.61941	.86056	.80674	.87550	.66162	.47840	.41414
1956	6305.44	.75645	.68394	.88033	.81063	.90493	.68018	.47642	.41045
1957	6351.19	.80355	.74006	.81997	.84824	.93896	.71436	.47138	.41365
1958	6788.40	.84224	.77663	.87304	.85084	.96306	.76830	.50754	.38849
1959	7334.71	.89657	.86274	.91051	.91958	.97417	.83934	.52030	.37321
1960	7912.48	.95314	.93612	.95733	.95979	.99061	.91902	.53120	.36083
1961	8516.46	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	.54381	.34605
1962	9018.66	1.05411	1.08231	1.01457	1.03632	1.01996	1.08533	.56077	.33966
1963	9508.12	1.11068	1.17461	1.00832	1.07393	1.03404	1.18984	.56139	.33353
1964	(10624.80) 10542.48	1.15909	1.31716	1.07804	1.12970	1.08451	1.32815	.56240	.32693
1965	11207.00	1.22822	1.47436	1.06139	1.17121	1.10681	1.49990	.55286	.32925
1966	11954.20	1.30609	1.68434	1.04475	1.22827	1.14085	1.16877	.54302	.33698
1967	12710.98	1.38312	1.84266	1.04058	1.29702	1.17371	1.86844	.54079	.34058
1968	13814.10	1.46568	2.06511	1.08325	1.36057	1.21948	2.02744	.54614	.33406
1969	14940.40	1.55869	2.33437	1.04579	1.49416	1.28286	2.16342	.51402	.35802
1970	(16485.80) 16516.87	1.63899	2.63682	1.04891	1.62387	1.35211	2.28416	.49799	.37133
1971	17951.80	1.70956	2.69772	1.04058	1.80415	1.42019	2.40026	.48313	.38304
1972	20161.20	1.80454	2.96927	1.09157	2.06226	1.47653	2.52124	.47953	.39061
1973	(21221.70) 21190.30	1.91210	3.31628	1.00312	2.26329	1.56221	2.65447	.44558	.41442
1974	23168.40	2.00785	3.60503	1.00104	2.51621	1.74061	2.80468	.43407	.42485
1975	27376.70	2.07532	3.86421	1.18939	2.85473	1.91315	2.97195	.46178	.40606
1976	31304.50	2.17307	4.24442	1.32778	3.21920	2.01408	3.15081	.46977	.39508
1977	(36078.00) 34745.33	2.29155	4.68449	(1.53590) 1.41935	3.40726	2.12911	3.33422	(.48680) .46712	(.37808) .39259

Note : Parenthesized amounts represent erroneous value for figure immediately to its right

* Source : D. S. Evans and J. J. Heckman [26] p.276-277

APPENDIX

PART ONE: TABLES

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ability to correct for the over-and underestimates that are apparent in the begining and ending periods shown in Table 7.

Much is to be credited to the literature we have been examining, but we have also found its accomplishments to be attended by limitations in methodology and errors in execution. This needs to be taken into account by others who might want to go even further into the issues surrounding the breakup of the Bell System. For such persons we have included a discussion and a Table, Table A.3 in the Appendix, which provides corrections to the data recorded in Table A.1. Rechecking the source from which the data used by Evans and Heckman were derived, we discovered that costs (and cost shares) had been calculated on the basis of input prices with a 1967 base period but all of the prices for these same inputs that appear in the other columns of Table A.1 were adjusted to a different (1961) base period. There appears to be no good reason for these discrepant adjustments -- which probably resulted from some error or oversight by Evans and Heckman when preparing these data for the uses they were to make of them. In any case readers need to be alerted to the further possibilities of error even in the data used by Evans and Heckman as is noted in the parenthesized values in Table A.1.

Table 8 Results of Extrapolations

Year	Observed Cost	Goal Programming Constrained Regression		Evans and Heckman Regression	
t	C_t	$\widehat{C}_t$	$C_t - \widehat{C}_t$	$\widehat{C}_t$	$C_t - \widehat{C}_t$
1978	39217.25	38177.45	1039.80	41026.56	-1809.31
1979	44122.33	42616.64	1505.69	45095.15	-972.82

* Values used for technological change index were obtained by extrapolating the values plotted in Figure 4 to 1978 and 1979.

We leave aside the possible use of such inefficiency estimates, e.g., for regulatory purposes, since this would lead into a consideration of other approaches to this same topic[31]. Leaving this all aside, we can close on a somewhat different note as follows.

When discussing the limitations of Shephard's duality theory and the use of the translog function in [19], we noted some of the hazards that might be experienced by always adhering to functions that are "everywhere smooth" when dealing with realistic data -- especially when capacity limitations or other constraints are likely to be present, as in the case of AT&T and its subsidiaries during the period covered in this study. Stated differently, it might have been preferable to proceed in these studies with functions that are discontinuous in their derivatives, say, in exchange for other properties such as

[31] See, for instance, Dennis Thomas [41] for a discussion of Data Envelopment Analysis as a tool for use by the Texas Public Utility Commission.

it seems apparent that it might have been advisable to secure cross checks from other disciplines.

This kind of "residuals examination" does not end the possibilities. In fields like marketing, for instance, it is common practice to use "hold-out samples" with the thus reserved data then used to test predictive power and the stability of regression coefficients that were obtained from the other (non-reserved) data. None of this appears to have been done and the data also do not appear to have been checked in other ways. See Appendix.

For some undisclosed reason, Evans and Heckman did not use the data for 1978 and 1979 that were also available from Christensen et al [22], and this provides an additional opportunity for testing the regression by treating these data as if they formed a hold out sample.

The results of effecting extrapolations from our previously estimated regressions for comparison with these hold-out data are shown in Table 8. Evidently there is some improvement in the Evans and Heckman regression, although this is clouded by the fact that costs continue to be overestimated. The goal programming/constrained regression, on the other hand, continues to provide a lower bound to the observed data and hence our goal programming/constrained regression function can continue to be interpreted as an eficient frontier that yields an estimated inefficiency in the vicinity of 3% for the cost performance in both of these years.

Turning to more detailed examinations, it is evident that the behavior of the residuals for E-H is far from what would be expected from a multivariate normal distribution. Costs were always underestimated by the E-H regression from 1947 through 1958 and always overestimated from 1969 to 1977. Even worse, from a policy-prediction standpoint, is an apparent trend toward worsening estimates in the most recent periods.

This behavior raises serious questions about the statistical estimates and tests of significance that play such a prominent role in the Evans-Heckman discussions. Although their strong criticism of works by others does not appear to have been responded to in kind, this may have occurred because the authors of these other studies were all members of a discipline where the checks we are using are not commonly employed.[29] Simple analyses of residuals like those we have just completed might have helped, and the failure to do this might seem suprising to others in fields such as statistical quality control[30] where examination of residuals is almost routine. Here again, then,

---

[29] Although we have been members of the Econometric Society for many years, we have difficulty recalling any article published in the Society's journal that contained a detailed examination of residuals, such as we have just illustrated.

[30] We are reminded that when we worked in the U.S. Government's Division of Statistical Standards with W. Edwards Deming, the statistician and quality control expert, his constant advice was "Examine your residuals. Always examine your residuals!"

costs reported by Evans and Heckman are not correctly related to the price data in Table A.1.

A further problem arises in that the factor share values in Table A.1 were taken from [22] and are therefore also not consistent with the factor prices used by Evans and Heckman in Table A.1. Given all these difficulties it seemed best to start afresh which is what we did to produce Table A.3.

The data in Table A.3 are drawn from Christensen et at [22] except for the local and toll outputs and the R&D Index, which are not given in [22]. The latter values are obtained from Table A.1 by dividing each of these columns by their 1967 values and transferring the results to Table A.3. In this manner all pertinent information is referred to a common 1967 base period with, of course, other base periods available if desired, by carrying out operations similar to the ones we have described.

PART THREE: DERIVATION OF CONDITON (v)

The constraint (v) is derived here in the following manner by starting with

$$\frac{\partial C}{\partial p_i} = \frac{\partial \ln C}{\partial \ln p_i} \cdot \frac{C}{p_i}$$

and

$$\frac{\partial^2 C}{\partial p_i^2} = \frac{C}{p_i} \frac{\partial}{\partial p_i} \left(\frac{\partial \ln C}{\partial \ln p_i} \right) + \frac{\partial \ln C}{\partial \ln p_i} \frac{\partial}{\partial p_i} \left(\frac{C}{p_i} \right) .$$

We use (1) in Section 1 to define a new variable Y via

$$Y = \frac{\partial \ln C}{\partial \ln p_i} = \alpha_i + 1/2 \sum_{j \neq i} \gamma_{ij} \ln p_j + \gamma_{ii} \ln p_i + \sum_k \rho_{ik} \ln q_k + \lambda \ln T$$

and we require

$$\frac{\partial^2 C}{\partial p_i^2} = \frac{C}{p_i} \frac{\gamma_{ii}}{p_i} + Y \frac{p_i \frac{\partial C}{\partial p_i} - C}{p_i^2} \leq 0$$

or , since $p_i^2 > 0$,

$$\gamma_{ii} C + Y \left[p_i \frac{\partial C}{\partial p_i} - C \right] \leq 0 .$$

For any $C > 0$, this last expression can be changed to

$$\gamma_{ii} + Y \left[\frac{\partial \ln C}{\partial \ln p_i} - 1 \right] \leq 0$$

or

$$\gamma_{ii} + Y^2 - Y \leq 0 \ .$$

Equivalently we then have

$$Y - \gamma_{ii} \geq Y^2$$

which we weaken to

$$Y - \gamma_{ii} \geq 0 \ .$$

Direct substitution and collection of terms produces the conditions displayed in (v) for each $i=1,2,3$, viz,

$$\alpha_i + \gamma_{ii}(\ln p_i - 1) + \sum_j \gamma_{ij} \ln p_j + \sum_k \rho_{ik} \ln q_k + \gamma_i \ln T \geq 0$$

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The recently implemented U.S. Court decision to break up Bell (American Telegraph & Telephone Co.) to accord with U.S. anti-trust laws is also proving to be influential in other countries. Econometric studies commissioned by the Anti-Trust Division of the U.S. Justice Department used "flexible functional forms" to demonstrate that the evidence failed to show that Bell was a "natural monopoly". This same evidence is reviewed via goal programming/constrained regression models to reach an exactly opposite

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conclusion. The two approaches are compared and shortcomings and deficiencies in the econometric modeling, statistics and statistical (optimization) principles utilized in the Bell System studies are examined in detail.

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